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(54) **Reduction in damage to optical elements used in optical lithography for device fabrication**

(57) An optical lithographic process and system for fabricating devices which includes an optical subsystem for reducing the rate of damage to the system's optics caused by exposure to energy pulses from an exposure source. The optical subsystem transforms a primary energy pulse from the exposure source into N secondary pulses, where N is $\geq$ 2 with a delay provided between each secondary pulse so as to reduce the peak intensity of the energy pulse being transmitted through the optical system. The subsystem redirects the secondary pulses spatially to satisfy source requirements for appropriate lithographic illuminators. Furthermore, the subsystem may be an intrinsic design feature of the illuminator or exposure source.

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expensive lements of the system. From the abov description, it is therefore desirabl to reduce the rate of damage to the optical system of projection printers and, in particular, to the projection lens of the optical system caused by exposur to DUV energy puls s, particularly as shorter wavelengths, photo resists requiring larger doses, or longer useful lens life becomes desirable.

Summary Of Invention

The invention is directed to DUV lithography systems and processes for fabricating devices which reduce the rate of laser-induced damage to optical elements caused by exposure to DUV radiation. In accordance with one embodiment of the invention, the reduction in the rate of laser-induced damage is achieved by reducing the peak intensity of each pulse without affecting average power output of the exposure source. Each primary output pulse from a pulsed DUV source is separated into a plurality of secondary pulses, including at least N secondary pulses where N is greater than or equal to 2. In addition, the intensity of the secondary pulses is about $1/N^{th}$ the intensity of the primary output pulse. The N secondary pulses are delayed in time so that the majority of the pulse energy of each secondary pulse is from each other, resulting in a sequence of N pulses with lower peak intensity for each primary output pulse. These secondary pulses are then appropriately directed through the optical train of the lithography system for imaging a mask pattern on a semiconductor wafer. By reducing the peak intensity of each pulse by N, the rate of laser-induced to the optical elements is reduced by about N times. Furthermore, these secondary pulses are formed quite efficiently using simple and insensitive illumination optics taht don't complicate or corrupt desirable characteristics of the laser or optics. Thus, the reduction in damage rate is achieved without substantially decreasing throughput, dose control, or imaging characteristics of the lithography system.

Brief Description Of Drawings

FIG. 1 is a simplified illustration of a conventional excimer projection printer used in the fabrication of devices;
FIG. 2 is a block diagram of the Divide and delay (DD) optical subsystem;
FIG. 3 is an illustrative embodiment of the DD optical subsystem;
FIG. 4 illustrates a multi-zone partial reflector of the DD optical subsystem of FIG. 3;
FIG. 5 illustrates a conventional DUV illuminator;
FIG. 6 illustrates a modified illuminator for receiving outputs from the DD subsystem;
FIG. 7 illustrat s a DD output interfac for spatially modifying the output of th DD system; and
FIG. 8 show an alternativ embodim nt of the DD optical subsystem.

Detailed Description Of The Inv ntion

The present invention relates to reducing laser-induced damage to optical elements caused by exposure to DUV en rgy pulses from an excimer laser. While illustrative embodiments of the invention are described with specific geometric configuration, it will be apparent to those skilled in the art that a variety of configurations which satisfy geometric requirements for proper lithographic illumination are also useful.

FIG. 1 is a simplified illustration of a conventional excimer projection printer such as a scanner or stepper for fabricating device. Such systems, for example, are described in Pol et al., Excimer Laser-based lithography: a Deep Ultraviolet Wafer Stepper, SPIE vol. 633, 6 (1986) and Unger et al., Design and Performance of a Production-worthy Excimer Laser-Based Stepper, SPIE vol. 1674, (1992), both herein incorporated by reference for all purposes. The projection printer comprises an excimer exposure source 110, a beam delivery subsystem 120, an illuminator 130, a mask 135 mounted on a mask frame 136, a projection lens 140, and a stage 150.

In operation, excimer laser 110 sends pulses through the beam delivery subsystem. Typically, the beam delivery subsystem comprises various mirrors and/or reflective elements such as lenses to direct the pulses into the illuminator. Optionally, the beam delivery system includes attenuators, shutters, and devices for providing energy or wavelength measurements, as known in the art. The illuminator receives the pulses and spatially manipulates the energy from the pulses to provide optimum illumination of mask 135, which contains, for example, circuit patterns. Projection lens 140 then projects the image of the mask onto a wafer 145 mounted on stage 150. The stage includes precision translation and rotation control by a computer (not shown) for accurate pattern alignment.

As previously discussed, fused silica, the material from which the optical elements of the DUV projection printers are often made, is subjected to laser-induced damage when exposed to DUV radiation. The rate of laser-induced damage (D) in fused silica, at least in the early phases before self-annealing or saturation takes effect, has been found to have a linear dependence with the number of pulses and a quadratic dependence with the peak power-density within a laser pulse. See Hibbs et al., 193-nm Lithography at MIT Lincoln Lab, Solid State Technology, July 1995, and Yamagata, Degradation of Transmission of Silica glass on Excimer Laser Irradiation, Journal of the Ceramic Society of Japan, volume 100 (1992). One example of formalizing D is as follows:

$$D = a^{*}E^{2*}J \qquad (1)$$

where E is the energy density p r pulse (mJ/cm^2) im-

reduction in th peak intensity of th primary pulses.

Various conventional techniques for delaying the secondary pulses can be employed. Such techniques, for example, provide separate beam paths for secondary pulses, each with different lengths to achieve the desired delay. Partial segmented reflectors, diffractive elements, or beam splitters may be used to provide separate beam paths. Given that the speed of light in air is roughly one foot per nanosecond, each successive secondary output pulse should travel an additional distance of at least about one foot for each nanosecond of delay. As such, to achieve a delay of a pulse width for a typical excimer pulse with pulse width of 20 nsec, the difference between each successive secondary pulse path is at least about 20 feet. It should be appreciated by those skilled in the art that various folding schemes using reflectors or mirrors can be used to provide secondary beam paths with different lengths to obtain the desired delay.

FIG. 3 is an illustrative embodiment of the DD subsystem 200 for splitting a primary input pulse P into secondary pulses P1, P2, and P3. The DD subsystem comprises an efficient reflector 320 and segmented partial (SP) reflector 340. Reflector 320 can be any conventional reflector used for reflecting DUV radiation. As pulse P enters the DD subsystem, it follows a path to the SP reflector which divides pulse P into P1 and P1a. The SP reflector passes P1 while reflecting P1a toward reflector 320. Reflector 320 then reflects P1a back toward SP reflector to divide P1a into P2 and P3. P2 passes through to the illuminator as P3 is reflected toward reflector 320. P3 is then reflected back at the SP reflector which transmits P3 to the illuminator.

Reflector 220 and SP reflector 340 are each spatially separated by a distance d. Illustratively, the geometry of the DD subsystem provides a delay for each successive beam path which is equal to about the time it takes for light to travel a distance of 2*d. For example, d is at least 10 feet to provide a delay of at least 20 nsec, which is the pulse width for a typical excimer pulse. Optionally, as well-known in the art, folding mirrors can advantageously be located within the beam paths to compress the size of the DD subsystem.

FIG. 4 illustrates SP reflector 340 of the DD subsystem used for splitting a primary pulse into secondary pulses. The SP reflector is made from, for example, fused silica 510 or other known suitable material. Such reflectors, for example are available from Rocky Mountain Instruments of Longmont, CO. Illustratively, the SP reflector is divided into three distinct zones, Z_1, Z_2, and Z_3. The zones are coated with conventional DUV reflective material using well-known coating techniques. The reflectivity of each zone is calculated to appropriately divide the beam into secondary output puls s with th desired intensity. Various t chniques which are known in the art can be used to achieve the desired reflectivity in each zone. In accordance to one embodiment, the reflectivity of each zone is chosen to produce secondary pulses of about th same total nergy l vel.

To provid outputs with relatively uniform energy levels, for example, within 10%, the dimensions of each zone should be large enough to capture the shape of the excimer pulse, which typically is about 5x20 mm. In one embodiment, the size of each zone is about 10-20% larger than the beam profile, leaving about a 1-2 mm boundary surrounding the beam. This is often useful in facilitating the coating process.

From the DD subsystem, the secondary pulses are input into the illuminator. FIG. 5 illustrates an embodiment of one type of conventional DUV illuminator 600. Such illuminators are described in Ichihara et al., Illumination System of an Excimer Laser Stepper, SPIE Vol. 1138, 137 (1989), which is herein incorporated by reference for all purposes. The illuminator comprises expanding optics 610, lens array 620, and a condenser lens 630. A pulse from an excimer laser passes through the expanding optics comprising, for example, cylindrical lenses 611 and 612. The cylindrical lenses transform the rectangular beam shape into a square beam to fill the lens array, such as a fly's-eye lens. Typically, the fly's-eye lens comprises 100 lenses or lenslets, e.g., 10X10 array. The fly's-eye lens samples or breaks up the beam into aerial portions associated with each lenslet. Each sample is diverged by the associated lenslet and then directed at the reticle by the condenser lens. The condenser lens is spatially located so that the lens allay is in its front focal plane and a mask 650 is in its back focal plane. Each lenslet in connection with the condenser acts as a telescope to expand the sample. The expanded profile samples are added at the reticle in such a way that the original beam profile averages out to a substantially uniform result.

The function of the illuminator is to provide substantially uniform illumination of the mask, both on a large scale and microscopic level. Non-uniform illumination can create undesirable interference patterns (i.e., "speckle") or large scale inconsistency in the image that is formed on the wafer. See Valiev, et al., The Optimization of Excimer Lasers Radiation Characteristics for Projection Lithography, JJAP Series 3, Proc. of 1989 Intern. Symp. on MicroProcess Conference, pp. 37, which is herein incorporated by reference for all purposes for a discussion on uniformity and coherence of the excitation source. Acceptable uniformity of the illumination depends on the fact that the emerging light from each lenslet is relatively incoherent. The many collimated and expanded beam samples from all the lenslet and condenser combinations overlap in the mask plane. Acceptable uniformity is achieved if the random profile structure errors in each sample tend to cancel when they are added in the intersecting plane. This requires that each sample be incoher nt so as to cause rapid random phase changes between the samples to r duce or eliminate potential interference patterns.

A problem with some conv ntional illuminators is that the expander optics used to fill th fly's-eye lens

Claims

1. A method for fabricating devices including imaging a pattern from a mask onto a surface of a wafer by illuminating the mask with an exposure source and transferring an image derived from the mask onto the surface of the wafer with a projection lens, the exposure source generates primary energy pulses of intensity I and pulse width T and wherein the primary pulses have a frenquency of F, the method comprising the steps of:

   dividing each of the primary energy pulse from the exposure source into a plurality of secondary pulses including at least N secondary pulses;
   incrementally delaying each of the N secondary pulses in time in order to decrease the peak intensity of the primary pulse so as to reduce the rate of laser-induced damage to the projection lens without essentially decreasing the average power output of the exposure source; and
   illuminating the mask with the N secondary pulses.

2. An optical lithographic system for fabricating devices comprising:

   an exposure source, the exposure source generating primary pulses of intensity I and pulse width τ and wherein the primary pulses have frequency of F, the system comprising:
   a divide and delay (DD) subsystem, the DD subsystem dividing the primary pulses from the exposure source into a plurality of secondary pulses, including at least N secondary pulses where N is equal to or greater than 2, and incrementally delaying the N secondary pulses in time, the incremental delay being sufficient to reduce the peak intensity of the primary pulses;
   an illuminator for receiving the N secondary pulses for illumination of a mask comprising a pattern; and
   a projection lens for transferring an image derived from the pattern of the mask onto a semiconductor substrate.

3. The method of claim 1, or the system of claim 2, wherein the incremental delay of the N secondary pulses is at least equal to about τ.

4. The method of claim 1 or the system of claim 2, wherein the N pulses are decoupled into N beam paths, which for example are substantially parallel.

5. The method of claim 1, or the system of claim 2, wh rein the intensity of each N secondary pulse is about (1/N)*I.

6. Th method of claim 1 wh rein the step of reducing damag to optical elements is an intrinsic feature of either an illumination system, or the exposure source.

7. The system of claim 2, wherein the DD subsystem reduces the rate of damage to the projection lens, for example by about 1/N times.

8. The system of claim 4, when appended to claim 2, wherein the DD subsystem comprises:

   a segmented partial reflector (SP) comprising at least N zones; and
   a reflector, the reflector and SP reflector is separated by a distance d and are geometrically configured to provide a folding scheme such that the primary beam pulse contacts a different one of the N zones and each time the primary pulse contacts one of the N zones, it incrementally travels a distance that is substantially equal to about the delay and wherein the reflectivity of each of the N zones are calculated to transmit at least a portion of the primary pulse from N to one of the N separate beam paths.

9. The system of claim 8, wherein the reflectivity of the N zones are calculated such that the intensity of the portion of the primary pulse being transmitted by the N zones is about equal.

10. The system of claim 8, wherein the DD subsystem comprises:

    a diffractor for separating the primary pulse into N secondary pulses each with a separate beam path; and
    a plurality of reflectors, the plurality of reflectors and the diffractor geometrically configured to provide a folding scheme such that each of the secondary beam path are incrementally greater to delay the N secondary pulses.

11. The system of claim 8 wherein the DD subsystem is incorporated either into the illumintor, or into the exposure source.

12. The system of claim 14 wherein the SP reflector and the reflector are consumable components to be routinely replaced.

FIG. 4

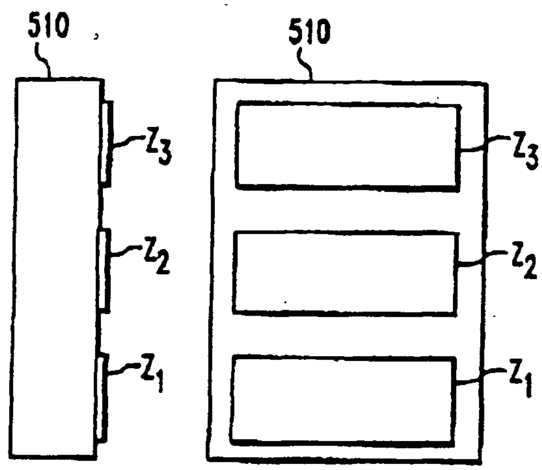

FIG. 5

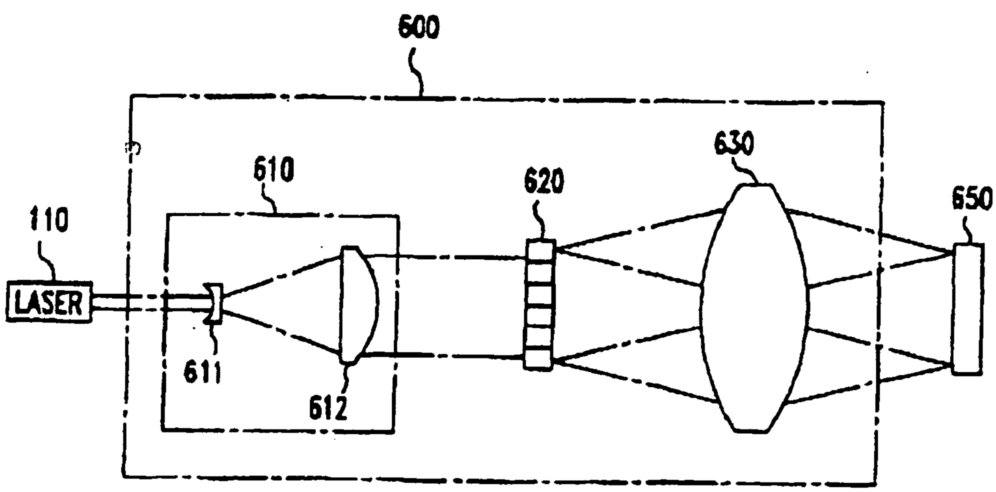

FIG. 8